Ultra-Long Duration Balloon Workshop Presentation

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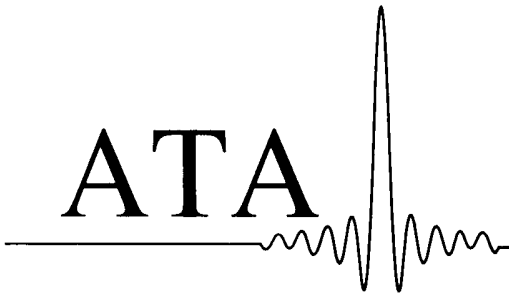
24-25 June 1997

Applied Technology Associates

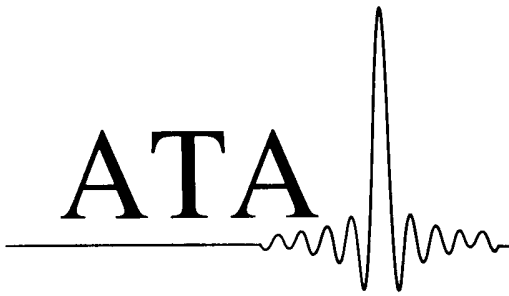
1900 Randolph Road

Albuquerque, NM 87106



Overview

- Pointing and Platform Stabilization
  - Expertise
  - Technology
- Balloon Control
  - Electronics



Pointing and Platform Stabilization

- ATA Has an Extensive Background in the Design and Application of Control Systems:
  - Acquisition, Tracking and Pointing Experiments
  - Platform Stabilization
  - Vibration Isolation and Control
  - Inertial Sensor Systems

ATA

Pointing Issues

- Required Accuracy?
  - 1 Arcsec Over Extended Period Can Be Difficult and Costly!
- How Long Must the Platform Maintain the Pointing Accuracy?
- Drift Requirement? (Low Rate Movement of Platform Over Time)
- Jitter Requirement? (High Rate Movement of Platform)
- Bias Requirement? (Average Offset)
- What Is Being Pointed?
  - Entire Platform or Steering Mirror
- Is the Platform Moving?
  - Hard to Measure Heading If Platform Is Stationary

Examples:

- Airborne Laser Laboratory (1975-83): Beam Control System
- Damper (1988-91): Demonstrate Electromagnetic Inertial Actuator to Control 6 DOF Motions of Micro-Gravity Experiments

⇒Wideband Angular Vibration Experiment (1986-92): Angular and Linear Vibration Measurement System on RME S/C

⇒High Altitude Balloon Experiment (1994-1997): Control System For ATP of Boosting Targets

- Advanced Pointer Tracker (1996-1997): Mount Control System Hardware and Software
- SNL Laser Pointing System-LAZAP (1996-1997): On-going Development of Mount Control Hardware and Software

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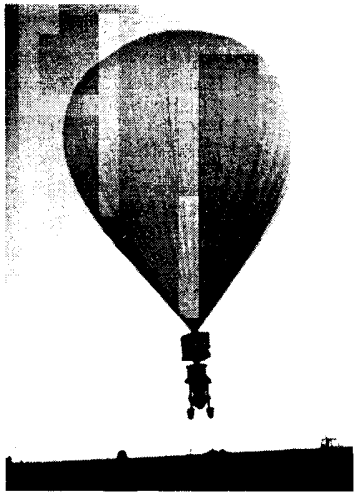
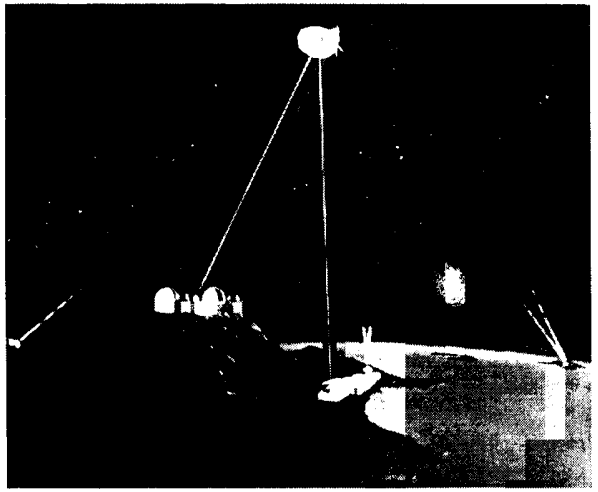
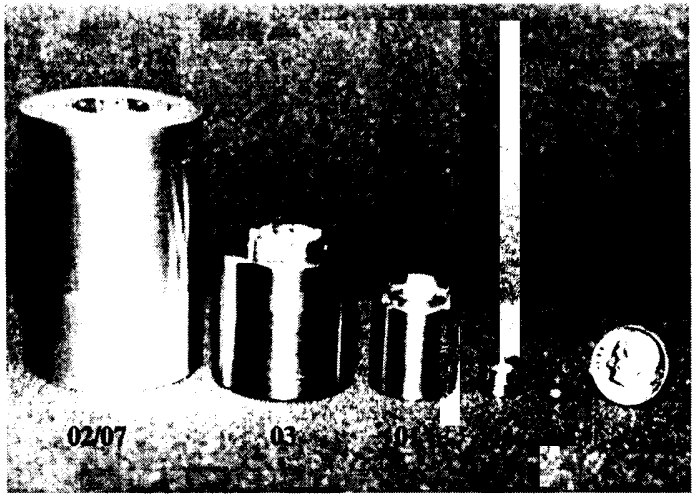
Is a Highly Stable Environment Required?



IPSRU and MHDs



WAVE (MHDs)



MHDs

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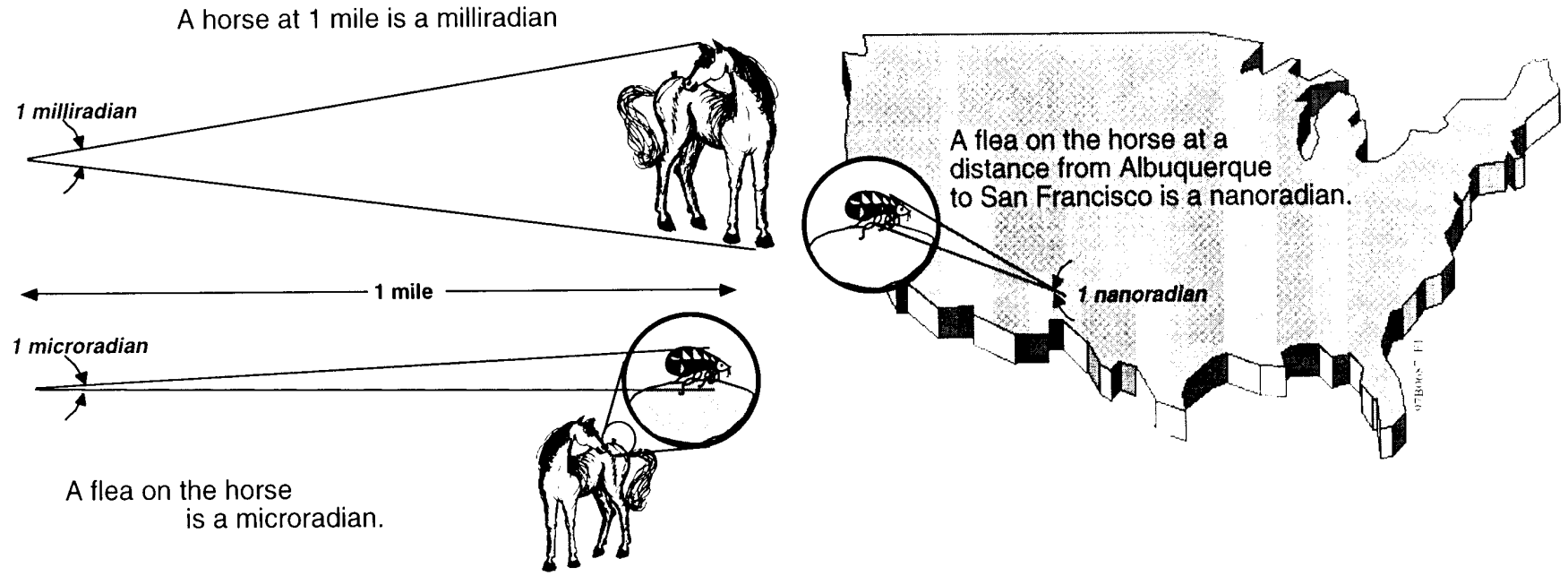
What is a Nanoradian?



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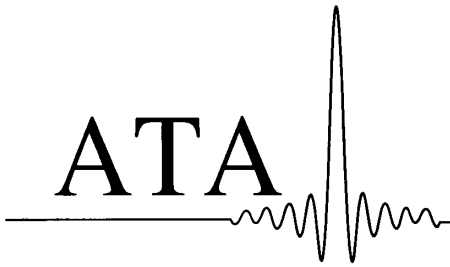
Arcsec to Radian Units

- 1 Arcsec = 4.8×10^{-6} radians

  or 4.8 μradians
- 1 Nanoradian = 1/4800 Arcsec

  or 2.08×10^{-4} Arcsecs
- So at a Mile an Arcsec is Like that Flea Being 4.8 Times Bigger
- We are Measuring 50 Times Better!



High Altitude Balloon Experiment (HABE)

- HABE Optical Platform:
  - Active (Laser Illuminated) Tracking System
  - IPSRU - Pointing Reference
  - Suites of ARS - 03 MHD Angular Rate Sensors (Test)
  - Suites of ARS - 02/07 MHD Angular Rate Sensors (Optical Platform)
  - QA-2000 Linear Accelerometers
- Marker Pointing Requirements: (Active Fine Track Mode)
  - Jitter: 333 nrad RMS - 4 sec Interval
  - Drift: 333 μrad - 4 sec Interval
  - Bias: 333 μrad - 4 sec Interval
  - Attitude Drift < 1 mrad/hour

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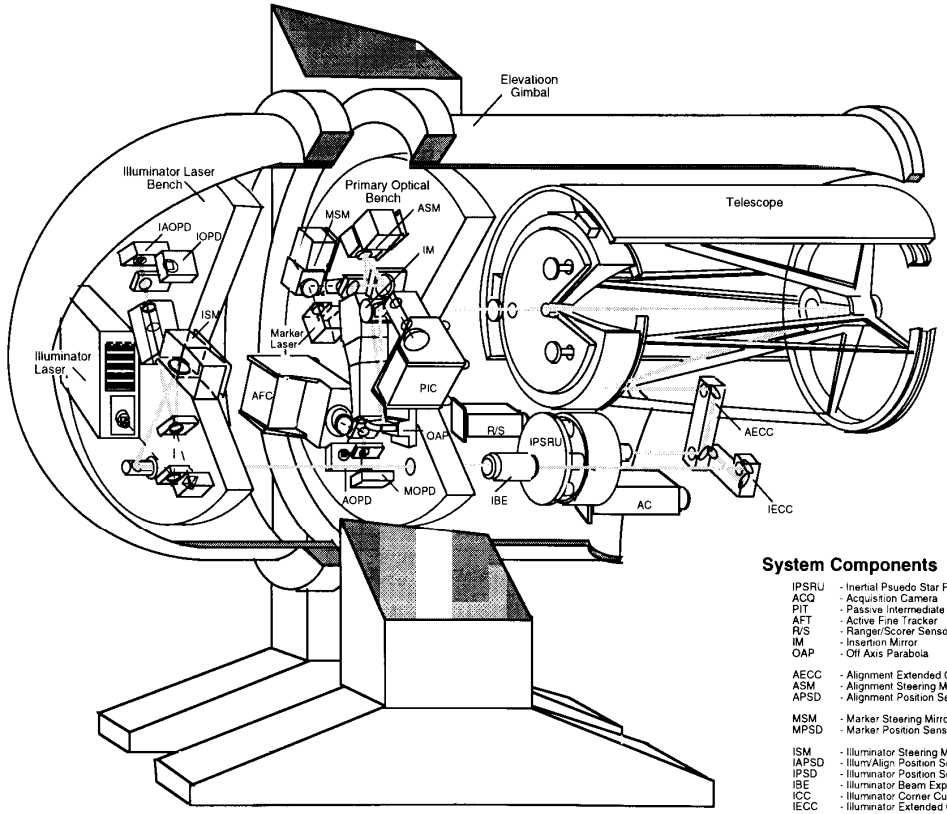
HABE Configuration



System Components

IPSRU	- Inertial Psuedo Star Reference Unit
ACQ	- Acquisition Camera
PIT	- Passive Intermediate Camera
AFT	- Active Fine Tracker
RVS	- Ranger/Scorer Sensor
IM	- Insertion Mirror
OAP	- Off Axis Parabola
AECC	- Alignment Extended Corner Cube
ASM	- Alignment Steering Mirror
APSD	- Alignment Position Sensitive Detector
MSM	- Marker Steering Mirror
MPSD	- Marker Position Sensitive Detector
ISM	- Illuminator Steering Mirror
IAPSD	- Illum/Align Position Sensitive Detector
IPSD	- Illuminator Position Sensitive Detector
IBE	- Illuminator Beam Expander
ICC	- Illuminator Corner Cube
IECC	- Illuminator Extended Corner Cube

- 360 Degree Azimuth
- ± 90 Degree Elevation
- ± 2 deg /sec Rate
- ± 1 deg / sec^2 Accel

- 60 cm Telescope
- Vis and IR Acquisition
- IR Intermediate
- Laser Enhanced Fine

- LOS Stability Goals
  - 333 nrads Jitter RMS
  - 333 nrads Bias/Drift

- 85,000 Feet Altitude

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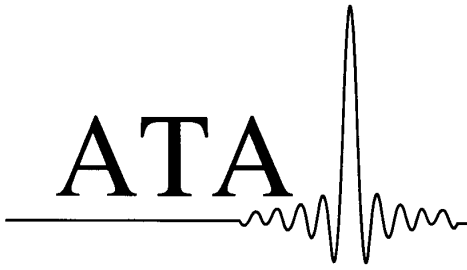
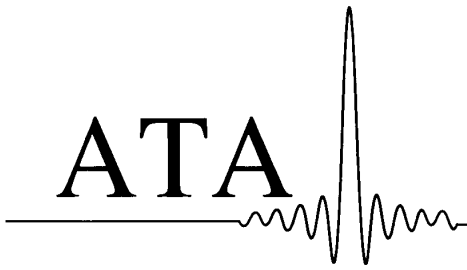


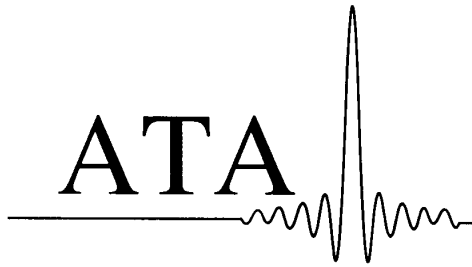
Key HABE Payload Features

- Four VME Processor Systems Perform Payload Tasks
  - » Line-of-Sight (LOS) Pointing, Alignment and Stabilization
  - » Downlink Telemetry
  - » Video Image Tracking
  - » Experiment Script, Mode Logic, Safety Monitoring
- Cameras Provide Target Tracking Signals - IR and Vis Acquisition, Infrared Intermediate, and Illuminated Precision
- Inertial Pseudo Star Reference Unit (IPSRU) Provides Precise Pointing and Alignment for Payload Cameras
  - » Initialized by GPS, Magnetometer, and Accelerometer Triad
  - » Stars Used to Update to Precise Attitude Measurement
  - » LOS Stabilized by Employing IPSRU Reference Laser and Digital Alignment Steering Mirror Loops (Operated at 16.2 Khz)
  - » Stabilized LOS in Precision Mode has Goal of 1/3 μrad RMS



Inertial Psuedo Star Reference Unit (IPSRU)

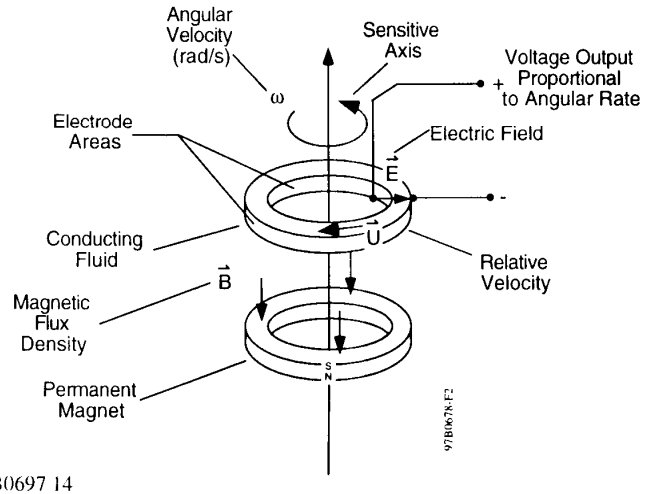
- Operation
  - Magnetometers and 'Gravitational' Vector Used as Reference
  - GPS and Star Pointing to Initialize Unit
  - Blending of ADS and Gyro to Provide Stable Platform
  - Additional Gyro Combined to Give Inertial Attitude and Position
- System Spec:
  - Jitter: Sub μradian
  - Drift rate: Sub μradian
  - Pointing Accuracy: Sub μradian
- Design Cost: ~$9 - 10M
- Replacement Cost: ~$3M



HABE Angular Motion Sensors

- ARS - 03:
  - ATA Patented Design
  - Specifications: 10 μrad RMS, 1 - 1 kHz Bandwidth, <0.3W, 260grams
  - Cost: $3,330 each
- ARS - 02 (ARS-07):
  - ATA Patented Design
  - Specifications:100 nrad, 3 Hz - 1 kHz, <0.3W, 400grams
  - Cost: $16,500 each

ATA's Magnetohydrodynamic Technology and Product Overview



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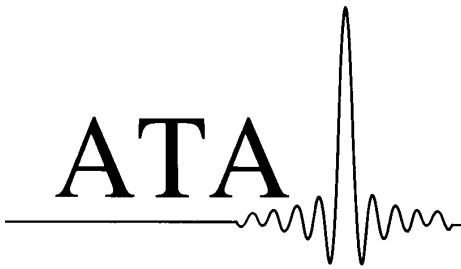
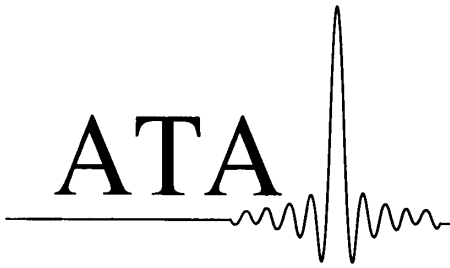
- We Have Developed a New, Exciting Sensor Technology for Angular Motion Measurement and Control Applications. Features Include:
  - Resolution to Millionths of Degree Accuracy Over a Bandwidth in Excess of 1,000 Hz
  - High Angular Rate Sensitivity
  - Low Cross-Axis Angular and Linear Acceleration Sensitivity
  - Rugged, Compact, Inexpensive, No Moving Mechanical Parts
  - Withstands Environments Where Conventional Gyroscopes Fail (in Excess of 3,000g)
  - Flexible, Custom Designs Available at Affordable Prices
  - Ideal Replacement for Conventional Gyroscopes



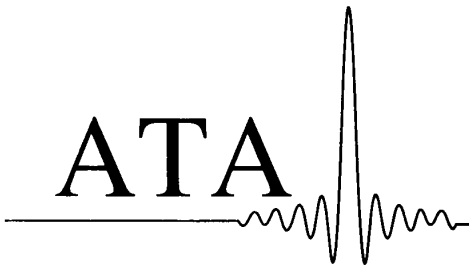
Sensor Technologies Expertise

Basis of Expertise			ATA's Contribution
Customer	**Year**	**Contract**	
Phillips Laboratory	1982-1985	Advanced Sensing of Angular Motion (ASAM)	Developed an inertial angular reference sensor for high energy laser beam control based on the MHD principle.
Phillips Laboratory	1986-1992	Wideband Angular Vibration Experiment (WAVE)	Developed the MHD Angular Rate Sensor--the cornerstone of the WAVE sensor suite for measuring ultra-low vibrations.
U.S. Army, U.S. Navy, DOT	1986-1996	7 Small Business Innovation Research (SBIRs)	Innovative applications of MHD Angular Rate Sensor technology for applications in autonomous navigation, proximity detonation, and automotive safety testing.
Toyota, Ford, GM, Hughes, Boeing	Established 1994	ATA Sensors	Created commercial division to sell magnetohydrodynamic (MHD) sensor products worldwide.



Wideband Angular Vibration Experiment

- Specifications:
  - Performance: < 100 nrad RMS, 1 Hz - 1 kHz
    <35 μg, 1 Hz - 1 kHz
  - Weight: ~ 27 lb
  - Size: 9.1"L x 9.1"w x 5.75"H
  - Cost: ~$0.5M



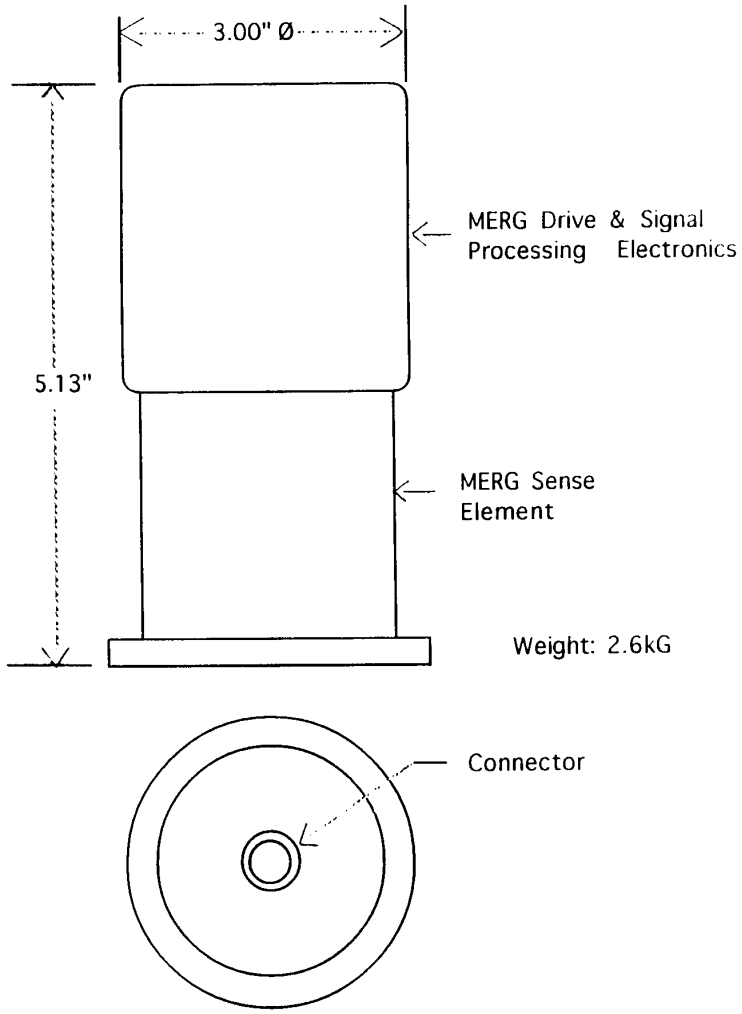
Technology Development

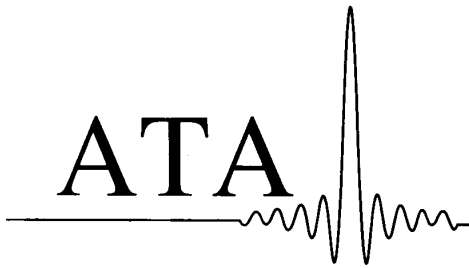
- MERG- MHD Effect Rate Gyro
- Northfinder

ATA

MERG Preproduction Model

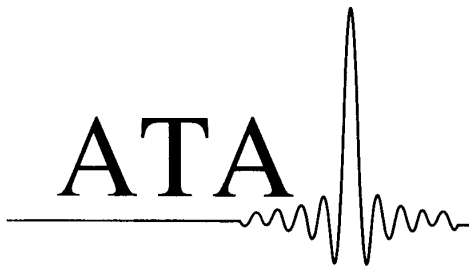
- Convenient Size Chosen to Maximize Engineering Validation and Investigation
- Design with Several Off-the-Shelf Components to Minimize Cost and Fabrication Time
- MHD Effect Rate Gyro
- DC Rate Response
  - Bandwidth DC 100+ Hz
- Designed for Land Navigation and Attitude Tracking
- Prototype MERG Demonstrated 5 deg/hour Drift





MERG Advantages Over Conventional Rate Sensor Technologies

- Innovative, Patented Rate Sensing Technology
- Extremely Reliable and Durable
  - No Moving Parts with the Exception of the Conductive Fluid
  - Designed to Work in High Vibration Environment
  - Can Withstand Same g Loadings as ARS-01
- MERG Prototype Exhibited Less than 5 deg/hr Drift Capability
- Potential of Being Produced at Much Lower Cost than Competing Technologies
- Can be Manufactured with Standard Machining Methods; No Expensive Assembly Procedures Required
- Flexible Design for Multiple Use Tailoring
- Off-the-Shelf Drive and Signal Conditioning Electronics



ATA's MERG Patent Technology Offers Future Gyro Replacement

- MERG - Magnetohydrodynamic Effect Rate Gyro
  - Patent Issued January 1993
  - Blends High Bandwidth Passive MHD Sensor and Active MHD Coriolis DC-Rate Measurement
  - Engineering Development Funded by Army - Phase II SBIR
- Features of MERG
  - No Mechanical Moving Parts
  - Proven Low Noise High Bandwidth (1,000 Hz or More)
  - NEA Demonstrated at 10 nrad RMS for 10 Hz and Above
  - Very Large Dynamic Range - No Physical Saturation
  - Goal of 1 deg/hour Drift for MERG Prototypes
  - Rugged and Reliable
  - Potential Cost Advantages
- MERG Provides Attractive Options for Optical Reference Inertial Stabilization - Either Strapped Down or Stabilized Gimbal

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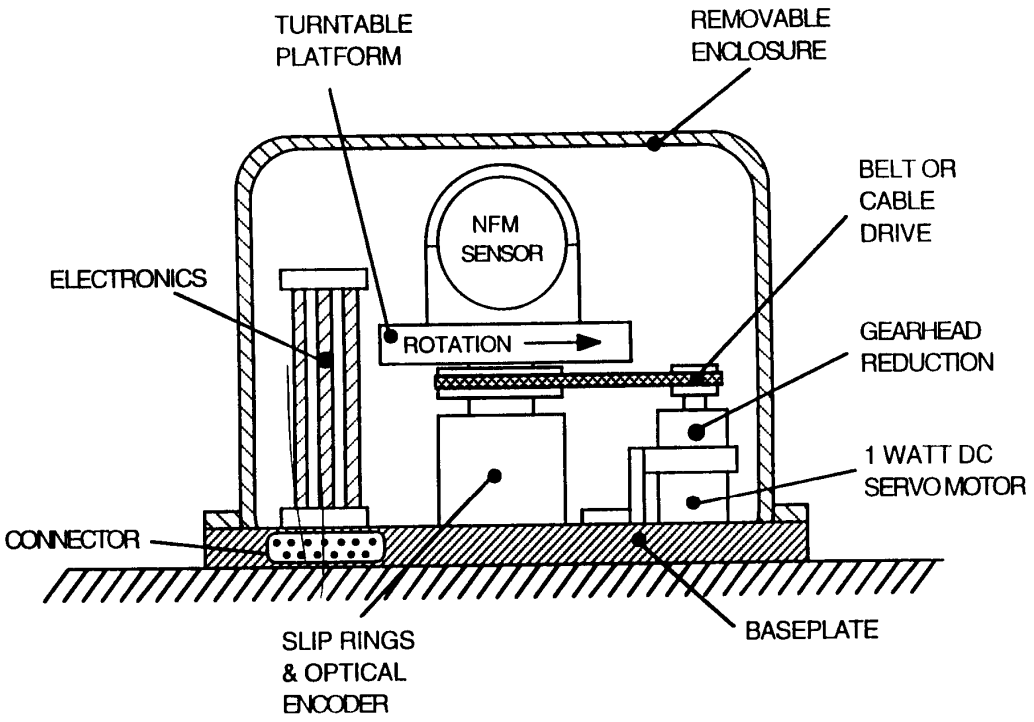
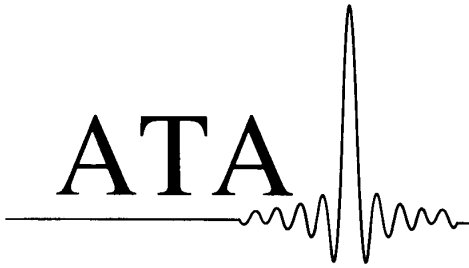
Northfinder (Spec and Picture)

- Proposed to Hughes as Component for Satellite Pointing/Stabilization System
- Lower Noise Floor than ARS-07
  - ARS-07 - 100 nrad
  - NFM ~30 nrad
  - Comparable to ADS - Systron Donner <100 nrad (1-1,000Hz)
- Cost: <$5,000

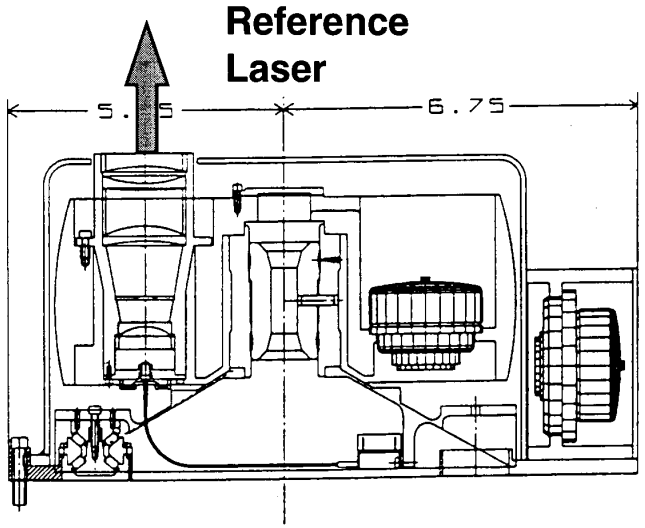




Potential Solutions

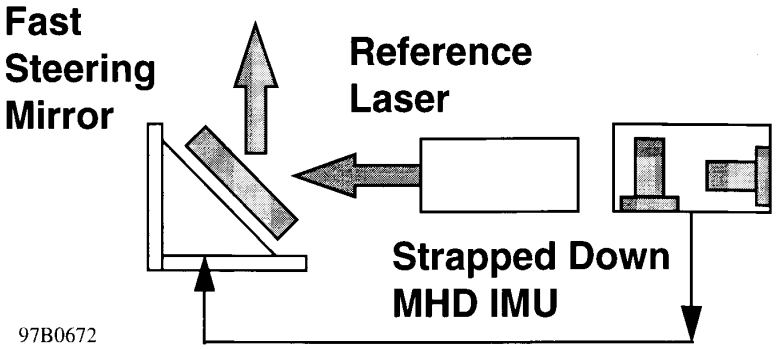
- IPSRU Type Replacement System:
  - Blending MERG and ATA MHD's or NFM
  - Blending another Gyro and ATA MHD's or NFM

ATA Reference for Precision Alignment and Stabilization



Inertial Pseudo Star Reference Unit (IPSRU Approach)

- Reference Laser Provides Stabilized Alignment and Pointing
- Two-Axis Gimballed Platform for Stabilization of Reference Laser



Stabilized Fast Steering MirrorApproach

- Reference Laser Provides Stabilized Alignment and Pointing
- Two-Axis Strapped Down Angular Rate Sensors for Stabilization of Reference Laser

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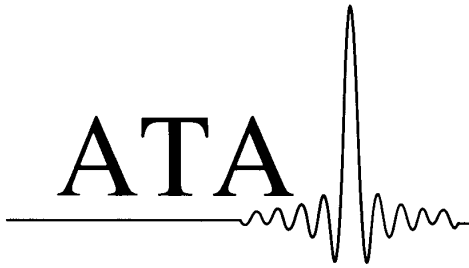
Optical Payload LOS Stabilization

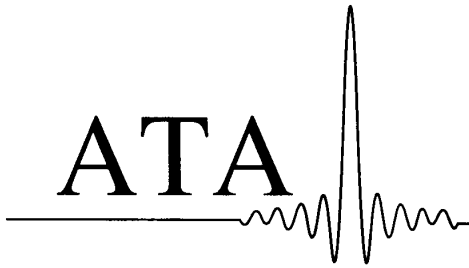
- HABE Utilizes a "State-of-the-Art" Instrument to Provide LOS Pointing, Stabilization, and Alignment - the IPSRU
  - » Less than 1 mrad / Hour Attitude Measurement Error
  - » Inertial Stabilization and Alignment Reference Less 100 nrads RMS
- Other Approaches for LOS Stabilization
  - » Utilize GPS, Magnetometer and Accelerometers for Coarse LOS Pointing and Low Performance wrt Jitter, Bias, and Drift
  - » Add Video Cameras, Image Processing, and Kalman Estimator which Filters Noise of Camera-Based Tracking Signals - Permits Low Bandwidth Stabilization and Pointing with Medium Performance
  - » Add Strapped-Down Inertial Angular Rate Sensors and Fast Steering Mirror to Provide High Bandwidth Alignment and Stabilization - One Notch Below HABE in LOS Stabilization Performance (Significantly Less in Cost)



Balloon Control

- ACTS: Acquisition, Control, and Telemetry System

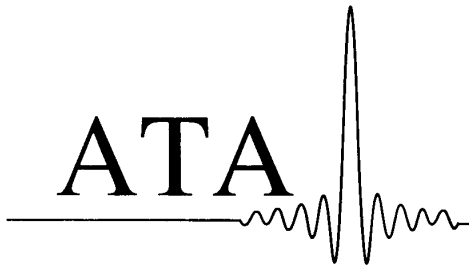
ACTS
Acquisition, Control, and Telemetry System



Introduction

- Phase II - Small Business Innovation Research Award
- Primary Requirement to Control and Monitor High Altitude Balloon Flight
- Provide Additional Processing Capability for Autonomy and Intelligence

ACTS
Acquisition, Control, and Telemetry System



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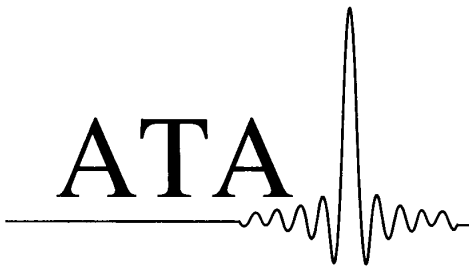
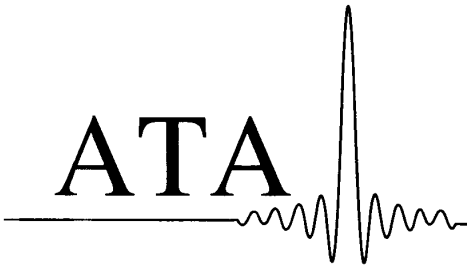


System Description

- Hardware:
  - Flight Hardware
  - Ground Hardware
- Software:
  - Payload Resident Software
  - Ground Station Software
  - Graphical User Interface

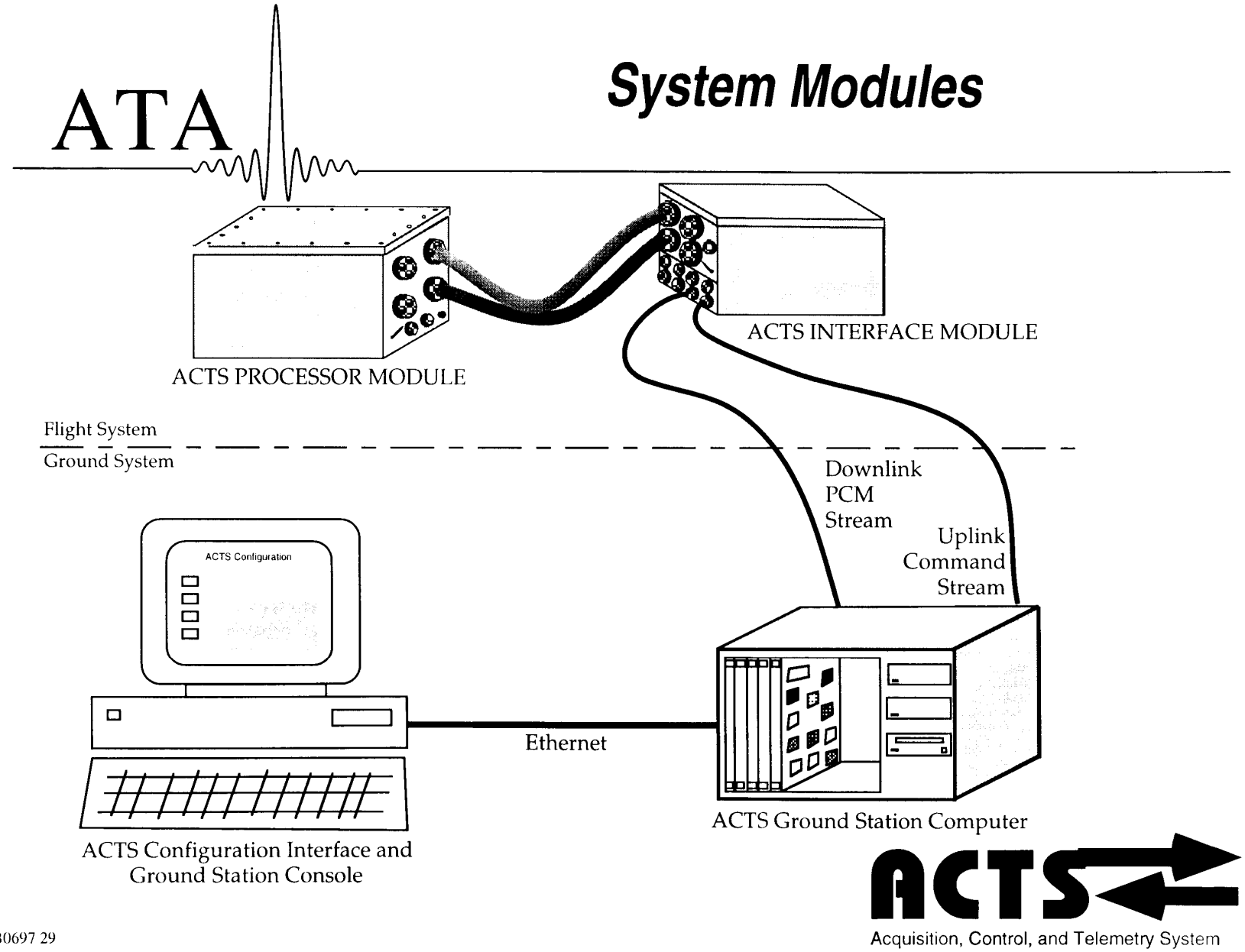
ACTS
Acquisition, Control, and Telemetry System



Flight Hardware

- Two Modules: ACTS Processor Module (APM), ACTS Interface Module (AIM)
- APM: Actual Flight Computer:
  - Component Selection:
    - Operation in Harsh Environment
    - Reliability
    - Low Power Consumption
- AIM: General Purpose and Flight Specific Electronics

System Modules



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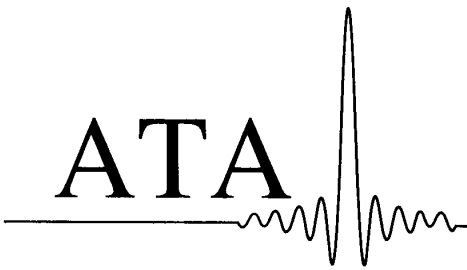

ACTS Processor Module

- Conductively Cooled Chassis and Boards with Ceramic Components
- Lightweight Aluminum Chassis, 9.5"L x 8.28"W x 4.5"H
- VME Based 68040, 25 MHz CPU, 4MB Ram, 2MB Flash
- Dual MC68302 Communications Boards, 6 serial ports
- Two 16-bit Digital I/O boards, 28- or 5V input logic
- 16 Channel, 12-bit A/D Board, 4 D/A outputs, 8 Dig I/O
- 24-bit TTL Level I/O Board (Custom Board AIM Interface)
- Operating at 1A, 28V

ACTS
Acquisition, Control, and Telemetry System

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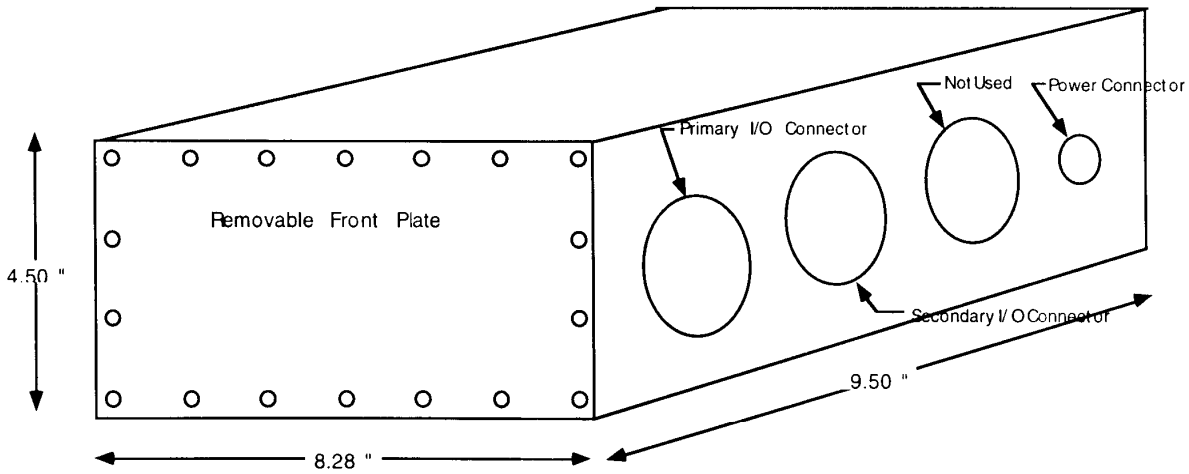
APM Physical Dimensions



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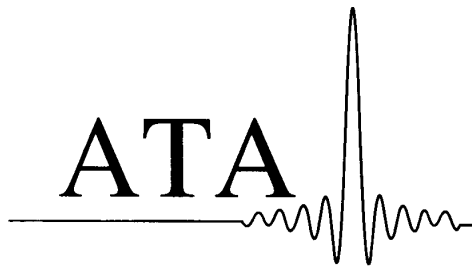
ACTS
Acquisition, Control, and Telemetry System



ACTS Interface Module

- Houses Balloon Interface Components Along with Suite of Communications Hardware
- Main Power Conditioning
- AIM Backplane and Cardcage
- Analog Expansion Card
- Digital Expansion Card
- Uplink Frequency Shift Keying
- GPS Receiver
- Relay Boxes
- Primary and Secondary RF Receivers
- Secondary RF Transmitter

ACTS
Acquisition, Control, and Telemetry System

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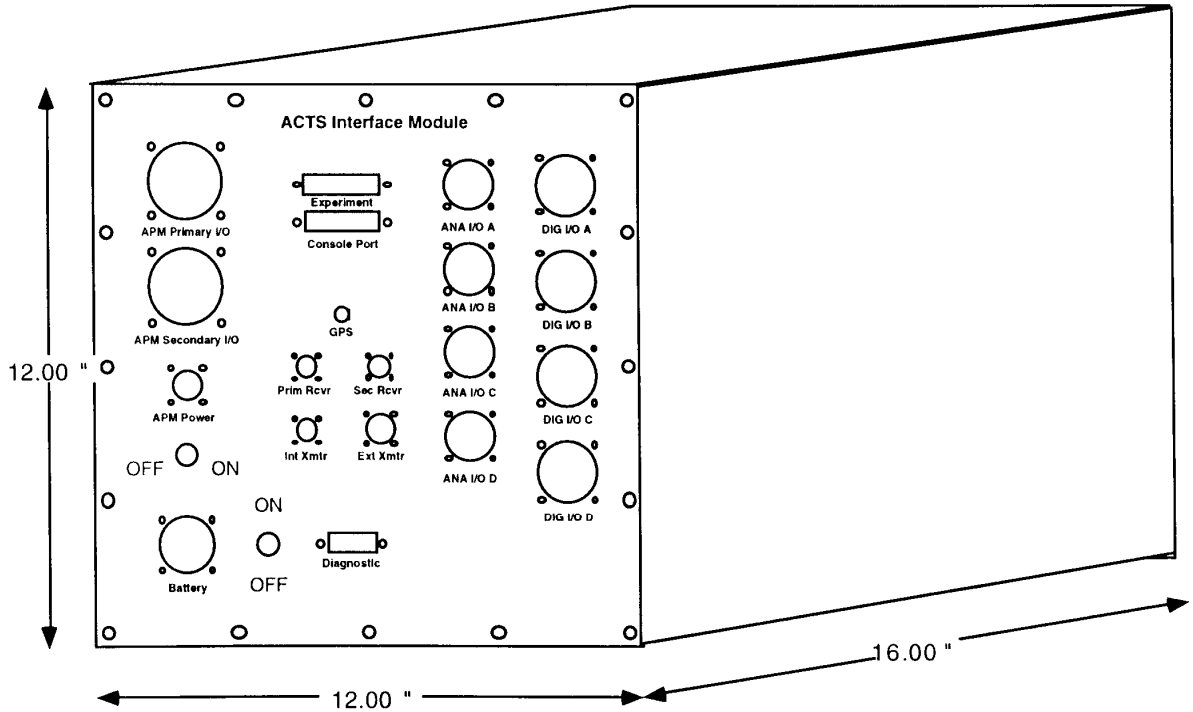
AIM Physical Dimensions



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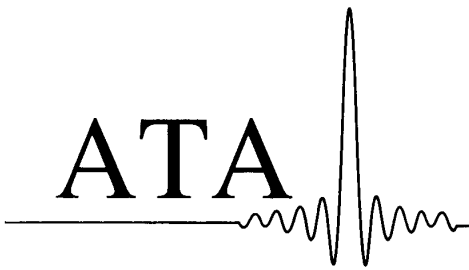


ACTS Ground Station

- Ground Computer:
  - 6U VME Chassis
  - MVME-162 Single Board Computer
  - Veda Bit Synchronizer Card
  - Veda PCM Decommutation Card
  - Custom FSK Modulation Card
- Ground Console:
  - 90 MHz Pentium-based PC
  - Linux Operating System
  - X11

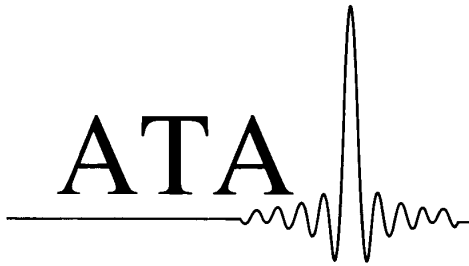
ACTS
Acquisition, Control, and Telemetry System

ATA

Flight Resident Software

- Running VxWorks Real-time Operating System
- All 'C' Code Except Assembly Start Up Routines
- Primary Functions:
  - Process the Uplink Command Stream
  - Generate Downlink Telemetry
  - Collect Analog and Digital Data
  - Control Digital Outputs
  - Monitor the GPS Receiver
  - Sequence through Predetermined Mission States
- Unique Software Feature is Ability to Execute Nearly Any Function

ACTS
Acquisition, Control, and Telemetry System



Ground Computer Software

- Running VxWorks Operating System
- Performs 3 Major Functions:
  - PCM Decommutation Card Configuration and Data Extraction
  - Uplink Command Stream Generation
  - Network Interfacing
- Idle Commands Sent at 10 per second
- Checksums in Uplink Packet to Ensure Data Integrity
- Data Extracted by Major Frame from Downlink
- Ground Console Requests Data and Ground Computer Periodically Transmits Over Network

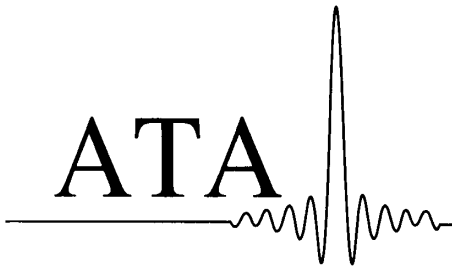
ACTS
Acquisition, Control, and Telemetry System

ATA

Graphical User Interface

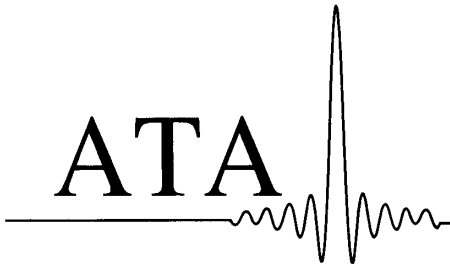
- Ground Console GUI - Under Linux and X11
- Blank Windows Modified by User to Fit a Mission
- Palette of Display and Control Elements for Placement Onto the Window
- Four Types of Elements Implemented
  - Analog Data Values in Scaled Engineering Units
  - Digital Data with Only High and Low Values (Enable/Disable)
  - Bar Graphs
  - Strip Charts
- Commanding Elements Currently Push Buttons
- File Saving and Multiple Screen Display Capability

ACTS
Acquisition, Control, and Telemetry System



Results and Lessons Learned

- Future AIM Designs to Be Developed With Simpler Cabling
- Set of Discrete Commands Should Be Added to Uplink to Allow Simple Switching Functions Without Need for APM (Restart APM or Firing Termination Squibs)
- Better Defined Command List With Thorough Verification by Ground Operator Incorporated Into Flight Software
- ACTS Originally Designed to Meet Balloon and Non-Balloon Applications. Review This Philosophy to Ensure a Highly Reliable System While Retaining Flexibility



ACTS Summary

- System at Prototype Stage
- Thermal Tested: -25°C to +60°C
- Flight Tested:
  - External Interface Blew Fuse Disabling ACTS
  - System Recovered - No Damage
  - System Performed as Anticipated Until Power Down
- SBIR Contract Ended - Final Briefing Conducted
- Air Force Presently Not Pursuing Long Duration Ballooning
- Additional Developments and Enhancements Identified for Final Version